National Aeronautics and Space Administration

NASA Case Study

GSFC-1011C – comp-1
Rev. 11/16/2015

The Calipso Mission, Project Management In The Pi Mode: Who's In Charge?

Figure 1: CALIPSO Observing Earth's Atmosphere. Source: NASA image.

The *CALIPSO* Mission was proposed in 1998 as a pioneering tool for measuring clouds and tiny airborne particles known as aerosols. Carrying the first lidar (light detection and ranging) polarization instrument into orbit, *CALIPSO* (*Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite* Observations)[1] would enable Scientists to build three-dimensional models of the Earth's atmosphere and to gain a better understanding of the planet's climate system. Among other uses, the models could be applied to pollution control and weather forecasting. See **Figure 1** for an artist's image of *CALIPSO*.

[1] See **Appendix 1** for a list of acronyms used in this case.

By the Spring of 2003, however, the Mission was facing a host of technical and organizational problems, the Project Manager had recently retired, and cancellation was not out of the question.[2] *CALIPSO* was a joint Mission between NASA and the French Space Agency *Centre National d'Etudes Spatiales*[3] (*CNES*) and had been hampered for years by a complex organizational structure and a difficult relationship between Langley Research Center (LaRC) in Hampton, Virginia, which was managing the Project, and the Goddard Space Flight Center (GSFC), near Washington, D.C., in Greenbelt, Maryland, which had Program oversight responsibility for the Mission. Communication issues, management turnover, international regulations, and instrument and Spacecraft problems had all presented obstacles. Now, the challenges had converged to push back the Project schedule, drive up costs, and threaten the very viability of the Mission.

Project Origins

First named *Picasso*, *CALIPSO* was proposed in 1998 by LaRC for NASA's second series of Missions in the Earth System Science Pathfinder (ESSP) Program. The Mission's proposed LIDAR instrument was the maturation of an experiment called LITE (LIDAR in-space technology experiment) developed in the early 1990s by Langley and carried in the payload bay of Space Shuttle *Discovery* in 1994.

LIDAR refers to *light detection and ranging* and is an optical remote-sensing technique similar to RADAR in that it involves bouncing a signal off of a target and using the reflected signal to determine range, motion, and densities of the target. The biggest advantage of LIDAR over RADAR is that the use of smaller wavelengths gives a LIDAR instrument the ability to capture information about airborne particles, which RADAR would not detect. Thus, LIDAR instruments are very useful for atmospheric research, among other uses for agriculture, archeology, and military purposes.

CALIPSO was the only outright selection from the proposals received in the Pathfinder announcement of opportunity (AO-02). *CloudSat*, whose radar measurements would complement *CALIPSO's* LIDAR observations, was the other eventual winner from the AO, chosen after a follow-up study and down select.

Once *CloudSat* was chosen, the two Missions agreed to formation-fly with the *Aqua* Mission of the Earth Observing System (EOS). They would also be co-manifested on a single *Delta II* launch vehicle.

With *CALIPSO* as the vanguard of the next generation of Earth Science Space Missions, expectations ran high. "For the first time," said Ghassem Asrar, NASA Associate Administrator for Earth Science, "We will be able to construct three-dimensional structures of the atmosphere to better understand the role of clouds and aerosols in Earth's climate."

[2] See **Appendix 2** for the Mission's timeline.
[3] For more information on *CNES*, see http://www.cnes.fr/web/CNES-fr/6919-cnes-tout-sur-l-espace.php. See **Appendix 3** for the case references.

Principal-Investigator (PI) Style of Project Management

When the Mission originated, NASA was in the early stages of moving toward the Principal Investigator (PI) mode of Project management—an approach advocated by NASA Administrator Dan Goldin. (*CALIPSO* was also conceived during the so-called faster-better-cheaper, or FBC, era.) The premise was that PIs chosen to lead space-science Missions would have complete responsibility for the Mission and that minimum Project guidance or involvement from NASA would result in more science returns.

There were two schools of thought about this method of management. One view held that the PI-mode would lead to increased competition among NASA Centers, ultimately benefiting the Agency. Specifically, in that view, the PI approach would develop Project-Management capabilities outside Goddard and the Jet Propulsion Laboratory (JPL), where most of the Agency's robotic space-flight Missions were centered.

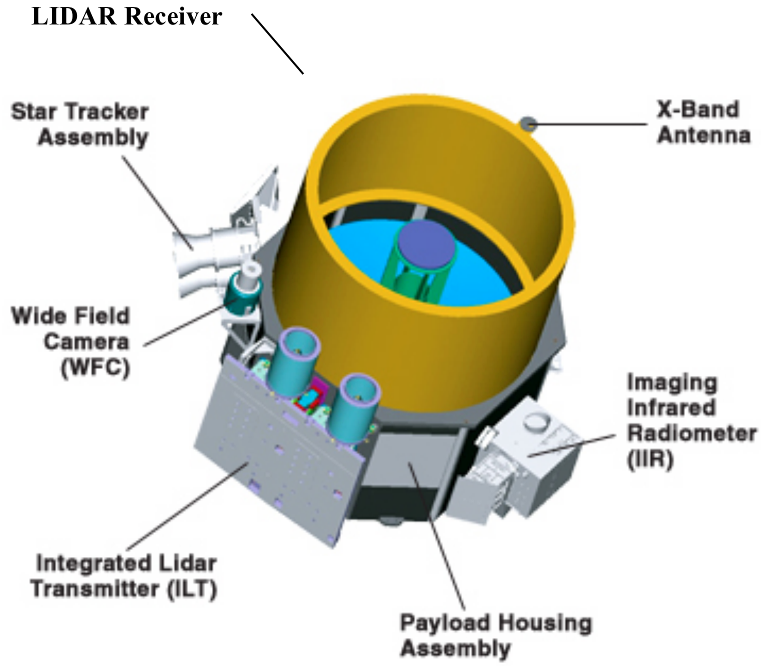


Figure 3: The CALIPSO Payload Module: LIDAR Telescope with Infrared Radiometer and Wide-Field Camera. *Source: NASA Image.*

The other view argued that flight Missions should be done only by Goddard and JPL, simply because it was too costly to replicate Project-Management capabilities elsewhere. This line of thinking had also led NASA to locate the ESSP Program Office at Goddard, even though some ESSP Projects were managed elsewhere. Goddard's extensive Project-Management expertise was to be leveraged through the Program Office on all ESSP Projects.

CALIPSO had been proposed by Langley and the PI was located at Langley. However, the Project was funded, like all other ESSP Missions in the Program, through the Program Office at Goddard. Based on the emerging PI mode of management, however, the Program Office was expected to apply only light-touch oversight to the *CALIPSO* Mission, allowing the PI Team to manage it. This was in accordance with the AO:

> *"The Principal Investigator and Mission Team will have full responsibility for all aspects of the Mission, including instrument and Spacecraft definition, development, integration, and test; launch services (if acquired by the Mission Team) or Mission-Launch interfaces (if launch service is NASA provided); ground system; science operations; Mission operations; and data processing and distribution…. It is the intent of NASA to give the*

PI and the Mission Team the ability to use their own processes, procedures, and methods, to the fullest extent possible."

Project Organization Structure

Notwithstanding the announcement of opportunity, the Centers running *CALIPSO* took very different positions on the responsibility for Project management. The Langley Director was interested in his Center gaining prowess in full-flight Mission-Project management. Further, as funding for aeronautics was decreasing, LaRC envisioned Earth science as a growing piece in its budget pie. The Director wanted to bypass the Program Office at GSFC and report directly to NASA Headquarters (HQ); he made his request many times. The Director's logic was that LaRC deserved a chance to prove itself in Flight-Project management, just as it had over the years for flight-instrument management.

The GSFC Director, on the other hand, took the position that Goddard had a proven, and current, track record of Flight-Mission management. By contrast, Langley had not managed a full-flight Mission, since the *Viking* journeys to Mars in the 1970s.

NASA HQ defined and confirmed the roles and responsibilities as follows. Langley, with its Principal Investigator leading the Project, would serve as the Mission Office and be responsible for the development of the primary science instrument. Goddard would provide high-level technical and programmatic oversight—again, with a light touch—through the ESSP Office and, in its role, as the lead Center.

Mission Partners

The *CALIPSO* Project structure was not confined to NASA and the United States. The Mission was a partnership with *CNES,* which included a Co-Principal Investigator role from the French research organization *Institut Pierre Simon Laplace*,[4] named for the great French Mathematician and Astronomer, who in the early 1800s theorized about black holes.

Under the NASA–*CNES* memorandum of understanding (MOU), which was not officially signed until June 2003, *CNES* would provide a number of components and services, including the ground stations, Satellite operations, and tracking, as well as integration of the payload onto the Spacecraft Bus and for Satellite-Level testing. *CNES* was also responsible for one of the three science instruments, the imaging infrared radiometer (IIR), to be built by the French firm Sodern, and for providing the *Proteus* Spacecraft Bus, to be built under a fixed-price contract by the French company, Alcatel, located in Cannes, France. See **Figure 2** for a diagram of the organizational structure.

Also on the Team was the U.S. firm Ball Aerospace & Technologies Corp. (BATC). Under a cost-plus-award-fee contract to Langley, BATC was responsible for designing and building the CALIOP LIDAR (cloud-aerosol LIDAR with orthogonal polarization), the main instrument on the Satellite (see **Figure 3**). Ball was also contracted to deliver a wide-field camera (WFC), the third instrument in the payload. Its facility in Boulder, Colorado, would serve as the location for integration of the three instruments onto a payload module. The company was responsible for delivering all ground equipment to

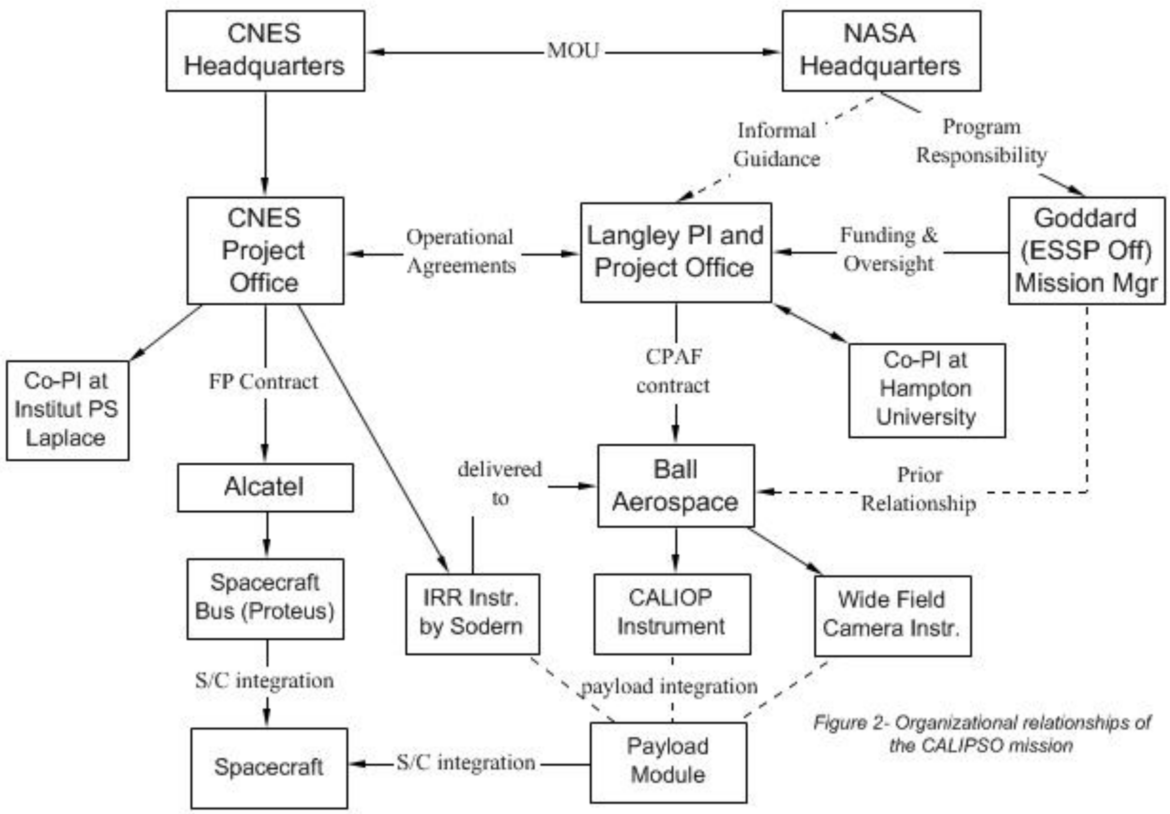
[4] For more information on *Institut Pierre Simon Laplace,* see http://www.ipsl.fr/en.

test, calibrate, and install the payload module onto the Spacecraft Bus. In addition, BATC would support Langley in the interface definition between the payload module and the Bus and in the installation of the payload module onto the Spacecraft at the Alcatel facilities. Given the number and disparate location of the Mission's major players, the potential for unwieldy management was a risk.

Management Challenge

During the early phases of *CALIPSO*, implementation went along relatively normal lines, and Goddard followed the light-touch approach to oversight. The Mission Manager (MM) was located at Goddard and reported to the Program Office there. He interacted with the Project Office at Langley, and served as the conduit for technical support as requested by Langley and Project oversight for the Program Office at Goddard.

Figure 2: Diagram of the Organizational Structure. Source: NASA.



This approach was consistent with other Missions in which LaRC had been responsible for delivering instruments to GSFC-managed Projects. And prior to *CALIPSO*, LaRC had partnered successfully with Program-Office Mission Managers at other locations, including NASA HQ and Johnson Space Center, as well as at GSFC. For example, the CERES (clouds and the Earth's radiant energy system) instrument had been developed at LaRC and flown on the Goddard-Led *Terra* and *Aqua* Missions. LaRC had also engaged successfully with Russian, French, and Italian firms in cooperative endeavors for instrument deliveries.

But questions about the management organization persisted among the Langley Team:

1. *If the Project was centered at Langley and reported to the Program Office at Goddard, why was the Project Manager at Langley reporting to the MM instead of directly to the Program Manager at Goddard?*
2. *If the MM was to be part of the Project Team—as the Program Manager had said—why wasn't he located at Langley?*
3. *For that matter, why have an MM at all if his only function was to act as a link between the Program Manager and the Project Manager?*
4. *In the PI mode, wasn't the PI supposed to run the Mission? What did the original AO mean when one Center has Program responsibility and another has Project responsibility?*

Meanwhile, members of the Goddard Management Team had concerns, too:

1. *How could they be expected to be responsible for Mission management if they did not have the authority to oversee the overall schedule (and had little confidence in LaRC's schedule)?*
2. *How could they provide oversight when they didn't know what all the partners and Contractors were doing?*
3. *What was the overall responsibility split between the Program Office at GSFC and the Project Office at LaRC? What exactly was the role of the lead Center?*
4. *Who was HQ holding accountable for Mission success? Why wouldn't HQ clarify roles and responsibilities?*

Other issues were cropping up—the Langley Team, for example, was having a hard time getting the contract with BATC in place. Then, in the spring of 1999, the Associate Administrator for Earth Science issued a directive that lead Centers should take responsibility for running Mission Readiness Reviews (MRR) and certifying flight readiness. Now, it appeared that Langley and Goddard were equally responsible for the *CALIPSO* Mission. In that light, the GSFC Director felt it was even more necessary for Goddard personnel to be directly involved in *CALIPSO*—essentially, to have more oversight—if they were going to be held accountable for the outcome. In this climate, technical issues were bound to become intractable.

Later the *CALIPSO* Project Manager appointed near the end of Project development, reflected on the different backgrounds of the two Centers and their approaches to the Mission:

> *"What's good about Langley is their technical work. But this sometimes resulted in turning an engineering concern into a performance issue that had to be resolved before continuing. This made it difficult to stay on schedule. The consequences—mainly on the budget—of not holding a schedule were not always factored into 'work on the floor' decisions. One of the things that stood apart in how Langley did things is that management did a lot of hands-off delegating. Give somebody a job and expect it to be*

> *done. That was far from the way at Goddard. So the Langley Project was always being second guessed. The light touch went out the window. It created a tense environment."*

The Program Manager for *CALIPSO* in a later stage of development, considered the Principal-Investigator management approach:

> *"The PI mode has always been problematic. PIs tend to be scientifically competent and understand the community they're involved in. They need to rely on each organization's strengths, but they can't help but be thorough end to end. A good Project-Management Team will temper the PI by providing programmatic balance to technical/performance decisions."*

To gain confidence in the technical approaches LaRC was taking on the Project after the new directive from HQ, an increasingly large shadow Team at GSFC began to mirror Langley's work. Predictably, the feeling at Langley was, "They don't trust us." Within LaRC, some Team members felt they didn't have the complete support of upper management and wondered whether certain Senior Managers really wanted to get into Mission management at all.

At the same time, there was a sense among some Goddard Managers that Langley was keeping them in the dark. Despite frustration with the way the Program was being managed, the LaRC and GSFC Teams maintained good, productive, working relationships. According to members of both Teams, personnel at both Centers placed much of the blame for management confusion on NASA Headquarters.

At the technical level, problems were flaring up with the LIDAR, at BATC, and with the Spacecraft. It was known from the beginning that the CALIOP instrument would be a challenge. At Goddard, issues with the recent Vegetation Canopy LIDAR[5] (VCL) and laser development on the *Ice, Clouds, and Land Elevation Satellite (ICESat)* Mission[6] were still fresh, resulting in the Center being much more critical of the CALIOP instrument development on *CALIPSO*. For its part, Langley felt that its experience on the LITE Project and its joint effort with BATC and Fibertek developing and testing the risk-reduction laser more than adequately addressed Goddard's concerns.

BATC, meanwhile, was in the awkward position of having communication paths and relationships (and loyalties) with both LaRC and GSFC, a situation that often made feedback and prioritization difficult and inconsistent.

International problems

There were similar relationship issues with the foreign partners. In addition, the U.S. International Trafficking in Arms Regulation[7] (ITAR) was complicating the interfaces with *CNES* and Alcatel. Under ITAR restrictions, Langley was finding it hard to share information with the *CNES*/Alcatel Team, and the French representatives were sometimes required to leave Project meetings when ITAR-sensitive material was discussed.

---

5 For more information on VCL, see http://www.nasa.gov/offices/oce/appel/knowledge/publications/VCL.html.
6 For more information on *ICESat*, see http://icesat.gsfc.nasa.gov/.
7 For more information on ITAR, see http://www.pmddtc.state.gov/regulations_laws/itar_consolidated.html.

Language barriers also presented issues that afflicted the U.S.–French relationship. Later, the *CALIPSO* Project Manager, thought back on the challenges posed by the international partnership:

> *"With our relationship with the French, we had to sit down with them when there were problems—e-mail didn't work, telecons didn't work. What worked best was to go over there and sit down and discuss things. They didn't like being told, "Here's the problem and solution—take care of it." There were enough idiosyncrasies in the language barrier to make it difficult. For example, 'demande' in French means 'request,' not 'demand.'"*

The French were alternately frustrated and insulted. As a result, *CNES* at times refused to provide reciprocal information when requested. The GFSC Project Manager reflected on ITAR:

> *"Working the interfaces between the payload and the Spacecraft Bus was an enormous problem. This would not have been the case if it had been a wholly domestic Project, with a prime Contractor interfacing the instruments…. ITAR is a huge challenge to NASA international partnerships."*

To both the domestic and international partners, there was one overarching issue. The mixed management signals emanating from the two NASA Centers to BATC and *CNES* were confusing: Who was really in charge of the Project?

At the same time, problems with the *Jason* Spacecraft, the first *Proteus* Bus, had an impact on the *CALIPSO* Spacecraft that caused the Preliminary Design Review (PDR) to be delayed until July 2000, which, in domino fashion, pushed back the combined Mission PDR/MDR (Mission Design Review) from April 2000, to September 2000.

More than a year and a half after *CALIPSO* was chosen as the only direct selection in the second ESSP Mission series, heralding a new era of Earth science discoveries from space, Project leaders found themselves on the defensive. And critical Mission Reviews were approaching.

Fractious Reviews

The MDR panel was made up of experienced Senior Project Managers and Engineers, mostly from Goddard (or retired Goddard personnel), with one independent Consultant. The reviews, which were held over the course of five days in September 2000, did not go well. The Panel focused on what it saw as a lack of demonstrated management at Langley, especially in laying the groundwork with *CNES* and interfacing with the French agency. LaRC was heavily criticized on cost and schedule management issues. And with BATC presenting the bulk of the Project material, the Review Panel was left with the negative impression that Langley was not in control of its Contractor.

Overall, the GSFC Reviewers embraced the notion that LaRC suffered from inexperience with end-to-end flight systems. While the LaRC Team felt abused by the review process led by Goddard personnel, GSFC, feeling responsible for the Mission, was worried not only about the outcome of the Project, but also about Goddard's reputation.

Two months after the contentious Preliminary Reviews came the Mission Confirmation Review (MCR) at HQ to determine if the Project was ready to proceed from the formulation stage to full implementation. Based on the PDR/MDR, the outlook was not bright. By now—November 2000—serious reservations had surfaced concerning the Project plan and implementation.

Aware of the concerns raised about Project viability, HQ delayed the confirmation approval for several months, until the spring of 2001. Even after a successful Confirmation Review, cost and schedule issues continued to dog the Project for the next two to three years, with the threat of Project termination.

Management Upheaval

CALIPSO struggled forward, driven by a determined and dedicated Project Team. But by mid 2002, there was an unavoidable sense that a replan was needed. Periodic attempts to forge a new, more effective management relationship for the good of the Mission resulted in still more changes in Program/Project personnel at both LaRC and GSFC. The Program and Project launch readiness schedules differed by about a year. Technical glitches and failures in the instrumentation had occurred. There was friction between all parties, if not among Team Members themselves.

Finally, in autumn 2002, a new Mission Manager was assigned at Goddard and the Project underwent changes in the management ranks at both Centers. Then, in the spring of 2003, came still more changes: The Project Manager at LaRC retired, leaving a leadership void.

Rick Obenschain, the Goddard Director of Flight Programs and Projects at the time, would later size up the problematic development of the Mission:

> *"This was a situation that was so far off the tracks.... The job at hand was to produce a Mission. It would not be a success—a Mission success or a science success—until it was a management success."*

Threaded Hydrazine Fittings

Hydrazine is a highly toxic and dangerously unstable fuel used mostly in maneuvering thrusters on Spacecraft. It is dangerous for personnel to handle or work around (symptoms of exposure range from irritation of the eyes to seizures and coma in humans). Hydrazine liquid is also extremely reactive and contact with incompatible materials can spur spontaneous combustion resulting in a fire. It is therefore also a risk to flight instruments, if it were to leak. One aspect of risk mitigation for hydrazine involves the exclusive use of welded fittings for any conduits, since welded fittings have fewer potential failure modes than traditional threaded fittings. The *Proteus* Spacecraft bus used for *CALIPSO* (being built by Alcatel) called for the use of some threaded (AN) fittings on the hydrazine propulsion lines. While these had been used on other Spacecraft built by Alcatel in the past, NASA was relying on an Air Force Range Safety Requirement (in EWR 127-1) for the ELV prelaunch processing. See **Figure 4**.

The Goddard Safety Office had raised the issue of the use of threaded fittings not being compliant with the safety requirements as early as 2003, though it was not reported as a risk to the PMC (Goddard Program Management Council) until August 2005 and then it was carried as a Project-level risk for months.

Goddard Engineering also had concerns about the use of threaded fittings as early as 2002 stating in an e-mail:

> *"The Calipso hydrazine propulsion system is zero-fault tolerant design against leakage of toxic and flammable propellant. The design places personnel at unacceptable risk. The range safety team can provide their assessment of adequacy of this design in protecting their facility."*

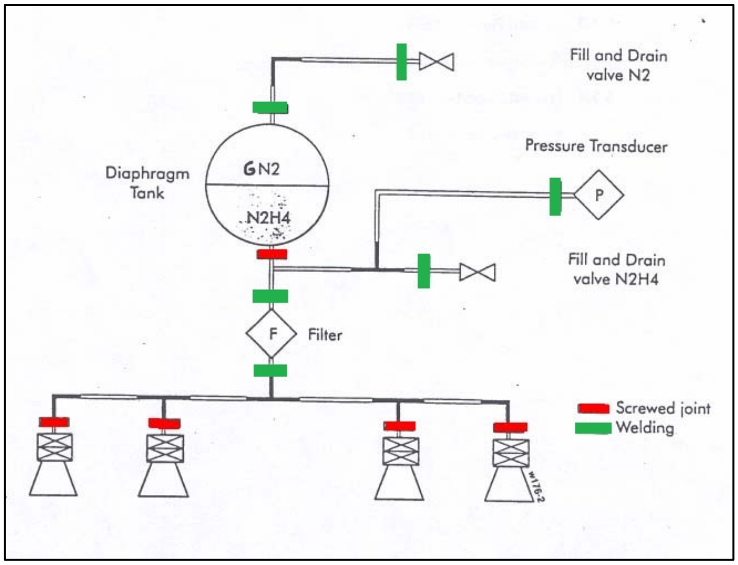


Figure 4: CALIPSO Propulsion System Simple Diagram. Source: NASA.

The Project Office and *CNES* had cleared the use of threaded fittings with the Air Force, which had authority over the range for the intended launch of *CALIPSO*. The Project was relying on the precedent of *JASON*, a previous Mission that used the same Alcatel Spacecraft bus including the threaded fittings. Though there was some lack of clarity on exactly how *JASON* had obtained clearance for the threaded fittings, the *CALIPSO* Project pointed to *JASON* as evidence that it was an acceptable risk. The Project assumed if the range was in concurrence then they could proceed. The Goddard Safety and Mission Assurance (SMA) Office and the Propulsion Engineering Branch did not feel the issue was closed nor did they feel that the claim of heritage to *JASON* was valid given the circumstances of how it was handled.

They thought the design should be changed or at least a waiver required especially since the Project should not be able to nullify the effect of a range safety requirement by proxy approval from the Air Force without NASA safety concurrence. Given the complicated organization structure and management challenges the Project faced, the issue remained unresolved. For example, Alcatel indicated they would be willing to make the change, but could only change the design if so directed by *CNES* (and provided additional funds). NASA could not pay *CNES* or Alcatel to make the change because of the nature of the HQ–*CNES* partnership, which allowed no funds transfers. As the launch date approached, this outstanding issue became a flashpoint between the partners.

Goddard SMA pointed to their Principles of System Safety and asked why they were being asked to compromise on accepted principles:

System Safety Principles

- If a system failure may lead to a catastrophic hazard, the system shall have 3 independent verifiable inhibits (dual fault tolerant).
  - A catastrophic hazard is defined as a condition that may cause:
    - death or permanently disabling injury
    - major system or facility destruction on the ground, or
    - Mission loss during operations.
- If a system failure may lead to a critical hazard, the system shall have 2 independent, verifiable inhibits (single fault tolerant).
  - A critical hazard is defined as a condition that may cause:
    - severe injury or occupational illness, or
    - major property damage to facilities or systems
- Hazards, which cannot be controlled by failure tolerance (e.g., structures, pressure vessels, etc.), are called "Design for Minimum Risk" areas of design.
  - Separate, detailed safety requirements
  - Hazard controls related to these areas are extremely critical
  - Warrant careful attention to the details of verification of compliance on the part of the developer.
- INHIBIT – A design feature that provides a physical interruption between an energy source and a function
  - Examples: a relay or transistor between a battery and a pyrotechnic initiator, a latch valve between a propellant tank and a thruster, etc.
- INDEPENDENT INHIBIT – Two or more inhibits are independent if no single credible failure, event, or environment can eliminate more than one inhibit.

When there are safety challenges, there is a systematic approach to dealing with them that allows for risk to be accepted when other options have been considered. Goddard SMA was looking at the requirement for two fault tolerance on hydrazine (due to its hazardous nature) and not seeing that the risk was adequately dealt with. The organizational structure did not allow an easy close to the decision and it lingered on as a concern. Though the Project largely considered it moot since the Air Force had responsibility for Range Safety, the question lingered on as a risk within the SMA and the Engineering Directorates at Goddard. As the Spacecraft approached final Flight Readiness, the SMA was still reporting a RED risk on their charts, which would be problematic for going forward to launch.

Hazard Reduction Precedence Sequence

1. **Design for Minimum Hazard**
   - Inherent safety through selection of appropriate design features as fail-operational/fail-safe combinations and appropriate safety factors
   - Hazards shall be eliminated by design where possible
   - Damage control, containment, and isolation of potential hazards shall be included in design considerations
2. **Safety Devices**
   - Hazards that cannot be eliminated through design selection shall be reduced to an acceptable level through the use of appropriate safety devices as part of the system, subsystem, or equipment
   - Relief devices, interlocks, safe/arm devices, protective barriers, etc.
3. **Warning Devices**
   - Employed for the timely detection of the hazardous condition and the generation of an adequate warning signal
   - Alarms, signs, etc.
4. **Special Procedures**
   - Includes personal protective equipment as well as written procedures
   - Least effective because dependent on human factors and behavior, which are often unpredictable

The Role of the NESC[8]

The GSFC Deputy Center Director requested the NASA Engineering and Safety Center (NESC) to independently review the *Proteus* propulsion bus design for personnel safety to determine what could be done, if anything, to make the existing design as safe as possible. At this point in time the only mitigations left available were level 4, which were special procedures. Clearly it is best to use level 1 and design things as safely as possible. For *CALIPSO,* it was too late for level 1, 2, or 3 by the time the issue was dealt with effectively.

The NESC formed a team of propulsion system and mechanical-fastener experts to evaluate the design. The team independently reviewed the design and build of the propulsion bus including a site visit to the manufacturer, Alcatel. In addition, the team performed independent testing of mechanical fasteners, material compatibility reviews, modeling and analysis of hydrazine leak detection capability, and a fire safety analysis.

Flight Readiness Report

In the Redbook (Flight Readiness Report) that Goddard prepared before the launch, the hydrazine leak was carried as a RED risk by the Goddard SMA and Engineering organizations. See **Figure 5**.

[8] More information about the NESC is available from the Web site at http://www.nesc.nasa.gov.

Figure 5: Residual Risk Chart. Source: CALIPSO Flight Readiness Report, GSFC April 12, 2006 p.13.

F=Flight Hardware and/or Facilities M=Mission Success P=Personnel Residual Risk	Project	SMA	AETD	IIRT
Hydrazine Leakage - Personnel	1,5	2,5	2,5	1,5
Hydrazine Leakage - Flight Hardware	2,5	3,5	3,5	2,5
Hydrazine Leakage – Mission Assurance	2,5	2,5	2,5	2,5
Excessive Battery Charge – Personnel	1,5	2,5	2,5	2,5
Excessive Battery Charge – Flight Hardware	1,5	2,5	2,5	2,5
Excessive Battery Charge – Mission Success	1,5	N/A	N/A	N/A
Use of SADM Without Life Test	2,5	2,5	2,5	2,5
Sample-and-Hold Chips	2,4	2,4	2,4	2,4

> "*The risk to flight hardware/facilities is also due to the possibility of hydrazine leakage from the AN fittings during the launch campaign. This residual risk is mitigated by the customary safeguards in place at the launch site. No additional safeguards are provided by the Project, but the probability of leakage is deemed as low and has been documented in a Propulsion Waiver dated June 10, 2005. Unlike the additional safeguards applied to mitigate the personnel risk, the safeguards described in the waiver do not effectively mitigate the risk to flight hardware or facilities. Hence, the risk has been assessed to be a (2, 5) by the Project and the IIRT, and (3, 5) by the SMA and the AETD [Applied Engineering and Technology Directorate].*"

The NESC Report[9] recommended some risk mitigations mostly in handling Hydrazine on the ground to assure the safety of personnel. The NESC Team concluded that the *Proteus* propulsion bus design, assembly, and verification along with leak detection and other mitigations put in place at the launch pad were adequate to ensure personnel safety.

> *"The NESC acknowledges that welded joints are superior to mechanical fittings in preventing leakage, but attention to workmanship and proper verification of the joint integrity is required for both. Mechanical fittings do afford a greater degree of flexibility in the assembly and repair of tubing systems. However, a thorough risk assessment must be conducted early in the design process to arrive at a configuration that presents the overall minimum risk to personnel, the Mission, and the environment. During the course of the review, it was noted that the hydrazine system does not have a tank isolation valve. The NESC team acknowledges that the omission of a tank isolation valve in the*

9 *CALIPSO* Flight Readiness Report, GSFC, April 12, 2006, p. 15.

propulsion feed system is less safe during ground operations than a system that has the capability to isolate leaks; but while one may be safer, both can be made safe through proper hardware development and launch site processes. Again, a thorough risk assessment must be performed when designing the Spacecraft to make these configuration decisions."

Executive Summary of the NESC Final Report on CALIPSO.

Eventually, a waiver was written based upon the NESC Report and on implementation of the mitigations that Report recommended in order to assure adequate safety of personnel. The NESC did not make a final determination of the safety of the design itself. They put forth 11 recommendations for mitigating potential hazards to personnel during handling, which the Project then adopted. This 'solution' allowed for a waiver and the Project to move ahead toward launch.

Reflecting on the unresolved differences of opinion that plagued *CALIPSO* up until launch, Steve Volz, the HQ Program Executive commented on the different risk charts (See **Figure 6**) presented:

"These results hide a more fundamental issue. The disagreements are even wider than the 5x5 matrix shows. The parties could not even agree on the analyses to be used or the criteria for acceptable risk."

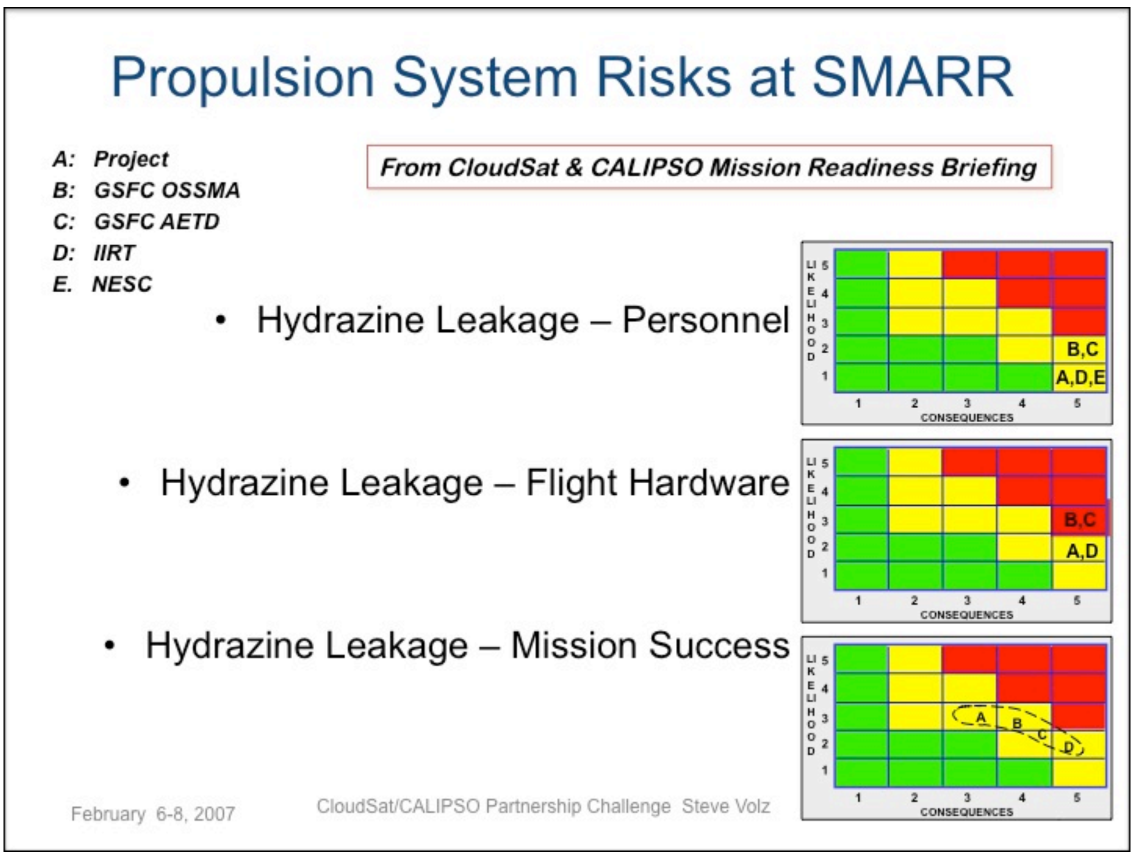


Figure 6: CALIPSO risk charts as presented at the MRR (taken from a HQ Lessons Learned presentation).

Later after the successful launch, the GSFC Deputy Director, Rick Obenschain opined:

> *"We spent $10,000,000 to solve a $100,000 problem, because the team wasn't on the same page. We have to take risks, but this isn't one we should pay for again."*

Appendix 1

Case Acronyms

AETD	Applied Engineering and Technology Directorate
AN	Threaded fittings
AO	Announcement of opportunity
BATC	Ball Aerospace &Technologies Corp.
CALIPSO	*Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite Observations*
CERES	Clouds and the Earth's radiant energy system
CNES	*Centre National d'Etudes Spatiales*
EOS	Earth Observing System
ESSP	Earth System Science Pathfinder
FBC	Faster better cheaper
GSFC	Goddard Space Flight Center
HQ	Headquarters
ICESat	*Ice, Clouds, and Land Elevation Satellite*
IIR	Imaging infrared radiometer
JPL	Jet Propulsion Laboratory
LaRC	Langley Research Center
LIDAR	Light detection and ranging
LITE	LIDAR in-space technology experiment
MCR	Mission Confirmation Review
MDR	Mission Design Review
MM	Mission Manager
MRR	Mission Readiness Reviews
MOU	Memorandum of understanding
NESC	NASA Engineering and Safety Center
PDR	Preliminary Design Review
PI	Principal Investigator
PMC	Program Management Council
SMA	Safety and Mission Assurance
SRR	Systems Requirements Review
VCL	Vegetation Canopy LIDAR
WFC	Wide-Field camera

Appendix 2

CALIPSO Mission-Development Timeline

Date	Event
December 22, 1998	Mission selection (originally called *Picasso*).
January 25, 1999	*Picasso* kick-off meeting at GSFC.
March 1999	Directive from NASA Associate Administrator for Earth Science: All lead Centers to use Program Management Councils to run MRRs for flight Missions, certify flight readiness.
April 19–23, 1999	*Picasso* Project kick-off meeting at LaRC.
May 1999	*CloudSat* co-manifested.
August 10, 1999	LaRC/BATC contract signed.
January 2000	Systems Requirements Review (SRR).
July 2000	*Proteus* Spacecraft PDR at Alcatel in France.
September 18–22, 2000	PDR/MDR.
November 15, 2000	MCR (confirmation delayed).
March 2001	*Delta* MDR.
April 2001	*Delta* Confirmation Review (Program/Project approval).
March 18–22, 2002	Critical Design Review (CDR) (also called Mission CDR).
September 2002	*Delta* Mission CDR.
November 2002	New Program Manager assigned at GSFC.
March 2003	Project Manager retires from Project and LaRC.
June 18, 2003	Signing of the memorandum of understanding between NASA and *CNES* for *CALIPSO*.
April 12, 2006	Flight Readiness Report from GSFC SMA Office calling hydrazine risk RED.

Appendix 3

Case References

Bothwell, Mary. "Walking a Fine Line." *Ask,* Vol. 17. Available at http://askmagazine.nasa.gov/issues/17/17s_fineline_bothwell.html. Accessed on December 12, 2012.

CNES. Available at http://www.cnes.fr/web/CNES-fr/6919-cnes-tout-sur-l-espace.php. Accessed on March 26, 2013.

Cox, Sylvia. "You Don't Have To Crash To Have Impact." *Ask,* Vol. 4. Available at http://askmagazine.nasa.gov/issues/04/04s_crash_cox.html. Accessed on December 12, 2012.

Ess, Kim. "Managing a Critical, Fast-Turnaround Project." *Ask,* Vol. 25. Available at http://askmagazine.nasa.gov/issues/25/25s_managing.html. Accessed on December 12, 2012.

Frasqueri-Molina, Taralyn. "Expecting the Unexpected." *Ask,* Vol. 43. Available at http://www.nasa.gov/offices/oce/appel/ask/issues/43/43s_expecting_unexpected.html. Accessed on December 12, 2012.

Guastaferro, Angelo (Gus). "Leaders' Responsibility To Develop Future Leaders." *Ask,* Vol. 24. Available at http://askmagazine.nasa.gov/issues/24/24i_leaders_responsibility.html. Accessed on December 12, 2012.

Little, Terry. "How Do We Work Together?" *Ask,* Vol. 9. Available at http://askmagazine.nasa.gov/issues/09/09f_work_little.html. Accessed on December 12, 2012.

NASA. *CALIPSO* Mission. Available at http://www.nasa.gov/Mission_pages/calipso/main/index.html. Accessed on March 26, 2013.

NASA. *CALIPSO* Flight Readiness Report, GSFC, April 12, 2006, p. 15.

NASA. *ICESat* Mission. Available at http://icesat.gsfc.nasa.gov/. Accessed on March 26, 2013.

NASA. NESC. Available at http://www.nesc.nasa.gov. Accessed on March 26, 2013.

NASA. VCL Mission. Available at http://www.nasa.gov/offices/oce/appel/knowledge/publications/VCL.html. Accessed on March 26, 2013.

Scolese, Chris. "Developing Engineering Excellence for Programs and Projects at NASA." *Ask,* Vol. 26. Available at http://askmagazine.nasa.gov/issues/26/26po_developing.html. Accessed on December 12, 2012.

Institut Pierre Simon Laplace. Available at http://www.ipsl.fr/en. Accessed on March 26, 2013.

U.S. Department of State. ITAR Regulations. Available at http://www.pmddtc.state.gov/regulations_laws/itar_consolidated.html. Accessed on March 26, 2013.